

Rotary transformerDescription

5 The invention relates to a rotary transformer as claimed in the precharacterizing clause of claim 1. The invention can be used, for example, in welding robots.

10 EP 0 722 811 B1 has disclosed a wireless robot having an apparatus for transmitting electrical power which comprises a rigid core bearing an articulated joint and having a primary winding around a proximal part of a rotary shaft and a rotary core having a secondary winding about a distal part of the rotary shaft, the
15 rigid core being positioned opposite the rotary core in contactless fashion, in order to transmit electrical power from the proximal part to the distal part in contactless fashion by means of electromagnetic radiofrequency induction.

20 EP 0 598 924 B1 has disclosed a contactless power transmission apparatus for a machine device, in which case power is transmitted from a stationary unit to a rotary unit of the machine device without any direct
25 electrical contact. A split core is used which comprises a first core and a second core, these cores being fixed to the stationary unit and the rotary unit, respectively, and forming a magnetic circuit, whose magnetic path length does not change as a result of any
30 desired rotation of the second core in relation to the first core. A first coil is connected to a radiofrequency AC source and is provided in the stationary unit in order to provide the magnetic circuit with a magnetomotive force. A second coil is
35 connected to a power-receiving apparatus and is fixed to the rotary unit, the second coil being arranged such that it is connected to a magnetic flux which passes through the magnetic circuit.

EP 0 680 060 A1 has disclosed a rotary transformer having an annular stator, which is U-shaped in cross section, and a rotor. The sleeve-shaped primary coil is
5 wound around the inner limb of the stator, while the likewise sleeve-shaped secondary coil conforms to the outer limb of the rotor, with the result that, whilst forming an air gap ensuring that they can move in relation to one another, the primary coil and the
10 secondary coil lie directly opposite one another.

Rotary transformers in accordance with the prior art have distributed windings, i.e. the primary winding and the secondary winding are located in core halves which
15 are separate from one another and in each case do not protrude beyond said core halves. On the one hand, a considerable leakage field is formed, and on the other hand the losses of the rotary transformer are relatively high.

20 The invention is based on the object of specifying a rotary transformer which has a relatively high degree of efficiency even when subjected to a radiofrequency - for example 25 kHz - and produces a relatively low
25 leakage field.

This object is achieved according to the invention, in conjunction with the features of the precharacterizing clause, by the features specified in the characterizing
30 clause of claim 1.

The advantages which can be achieved by the invention consist in particular in the fact that the skin effects occurring at high frequencies as well as the
35 transformer losses occurring and the leakage field occurring are minimized. This therefore results in a high degree of efficiency for the rotary transformer. The rotary transformer can be reproduced exactly, i.e.

the discrepancies in the electrical data occurring during manufacture are extremely slight. The air gap to be formed between the two core halves - important for the two transformer halves to be capable of moving in a rotary fashion freely with respect to one another - can be selected such that it has a relatively large dimension and has a negligible effect on the leakage field produced and the losses produced.

10 The primary part and the secondary part of the rotary transformer can be used at the same time as DC-isolated "contacts" in the sense of a plug; for example the primary part is located at the free end of one robot arm, which can be fitted with various tool arms. These
15 different tool arms each have the secondary part of the rotary transformer at their end which serves to fix it to the robot arm. It is possible for tools to be replaced in a simple and rapid manner, i.e. for various tool arms to be fitted to the robot arm.

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Further advantageous are described in the description below.

25 Advantageous refinements of the invention are characterized in the dependent claims.

The invention will be explained below with reference to the exemplary embodiments illustrated in the drawing, in which:

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figure 1 shows a section through a first exemplary embodiment of a rotary transformer having winding sections extending parallel to the axis of rotation,

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figure 2 shows a section through a second exemplary embodiment of a rotary

transformer having winding sections extending perpendicularly with respect to the axis of rotation,

5 figure 3 shows a section through a third exemplary embodiment of a rotary transformer having a plurality of annular cutouts in the core halves,

10 figures 4, 5 show perspective illustrations of exemplary embodiments with a central hole in the core, and

15 figure 6 shows the course of the magnetic field strength over the individual winding sections.

Figure 1 shows a first exemplary embodiment of a rotary transformer having winding sections extending parallel to the axis of rotation. In this embodiment, the primary winding and the secondary winding have in each case sleeve-shaped winding sections which interengage in the manner of a comb. This embodiment is advantageous in the case of rotary transformers in which the physical height is intended to be great in comparison to the diameter of the core.

The rotary transformer 1 has two essentially symmetrical core halves, to be precise a first core half having a base plate 2, an outer ring 3 and an inner cylinder 4 as well as a second core half having a base plate 5, an outer ring 6 and an inner cylinder 7. An air gap 8 is formed between the two core halves, with the result that the two core halves can move in rotary fashion with respect to one another about a common axis of rotation 9, which runs in the center of the inner cylinders 4, 7, without coming into contact.

As can clearly be seen in the sectional illustration shown in figure 1, the outer rings 3, 6, the inner cylinders 4, 7 and the base plates 2, 5 delimit a single annular cutout which is suitable for
5 accommodating (in each case preferably helical) windings. The individual winding sections of the primary winding and the secondary winding are in this case fixed in circular winding supports, which are in each case made from an electrically insulating
10 material, for example plastic, and are mounted on the inner sides of the base plates. The electrical connections between the individual, in each case sleeve-shaped winding sections run within the winding supports. Each winding has two winding terminations,
15 which are passed to the outside via the winding support and corresponding openings in the base plate.

A winding support 10, which is associated with the primary winding, is fixed to the base plate 2 of the
20 first core half and fixes, for example, five winding sections of a primary winding, to be precise

- an outer winding section 11,
- two immediately adjacent central winding sections 12, 13,
- 25 • two immediately adjacent inner winding sections 14, 15.

A winding support 17, which is associated with the secondary winding, is fixed to the base plate 5 of the
30 second core half and fixes five winding sections of a secondary winding, to be precise

- two immediately adjacent outer winding sections 18, 19,
- two immediately adjacent central winding sections 20, 21,
- 35 • an inner winding section 22.

A winding termination 16 of the primary winding and a winding termination 23 of the secondary winding can be seen (of course at least two winding terminations are required per winding).

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As is identified in figure 1, the current directions of the winding sections (which lie directly opposite one another so as to form an air gap and are associated alternately with the primary winding and the secondary winding) 11/18, 19/12, 13/20, 21/14, 15/22 are in each case opposite one another.

10 Figure 2 illustrates a second exemplary embodiment of a rotary transformer having winding sections extending perpendicularly with respect to the axis of rotation.

15 In this embodiment, the primary winding and the secondary winding have in each case circular winding sections which interengage in the manner of a comb. This embodiment is advantageous in the case of rotary 20 transformers in which the diameter is intended to be large in comparison to the physical height.

The rotary transformer 24 has two asymmetrical core halves, to be precise a first core half having a base plate 25 and an inner cylinder 26 as well as a second core half having a base plate 27 and an outer ring 28.

25 An air gap 29 is formed between the base plate 27 and the inner cylinder 26, and an air gap 30 is formed between the base plate 25 and the outer ring 28, with the result that the two core halves can move in rotary 30 fashion with respect to one another about a common axis of rotation 31, which runs in the center of the inner cylinder 26, without coming into contact.

35 As can clearly be seen in the sectional illustration shown in figure 2, the outer ring 28, the inner cylinder 26 and the base plates 25, 27 delimit a single annular cutout which is suitable for accommodating (in

each case preferably helical) windings. The individual winding sections of the primary winding and the secondary winding are in this case fixed in sleeve-shaped winding supports, which are in each case made
5 from an electrically insulating material, for example plastic, and are mounted on the inner side of the outer ring 28 or the outer side of the inner cylinder 26. The electrical connections between the individual, in each case circular winding sections run within the winding supports. Each winding has two winding terminations,
10 which are passed to the outside via the winding support and corresponding openings in the base plate.

A winding support 32, which is associated with the
15 primary winding, is fixed to the outer side of the inner cylinder 26 of the first core half and fixes, for example, five winding sections of a primary winding, to be precise

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- a winding section 33,
- two immediately adjacent winding sections 34, 35,
- two immediately adjacent winding sections 36, 37.

A winding support 39, which is associated with the secondary winding, is fixed to the inner side of the
25 outer ring 28 of the second core half and fixes five winding sections of a secondary winding, to be precise

- two immediately adjacent winding sections 40, 41,
- two immediately adjacent central winding sections 42, 43,
- 30 • a winding section 44.

A winding termination 38 of the primary winding and a winding termination 45 of the secondary winding can be seen.

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As is identified in figure 2, the current directions of the winding sections (which lie directly opposite one another so as to form an air gap and are associated

alternately with the primary winding and the secondary winding) 33/40, 41/34, 25/42, 43/36, 37/44 are in each case opposite one another.

5 Figure 3 illustrates a third exemplary embodiment of a rotary transformer having a plurality of annular cutouts in the core halves. This embodiment is in principle suitable both for sleeve-shaped winding sections - see figure 1 - and for circular winding
10 sections - see figure 2, but only one embodiment, corresponding to figure 1, is shown, with sleeve-shaped winding sections.

15 The rotary transformer 46 has two essentially symmetrical core halves, to be precise a first core half having a base plate 47, an outer ring 48, two intermediate rings 49, 50 and an inner cylinder 51 as well as a second core half having a base plate 52, an outer ring 53, two intermediate rings 54, 55 and an inner cylinder 56. An air gap 57 is formed between the two core halves, with the result that the two core halves can move in rotary fashion with respect to one another about a common axis of rotation 58, which runs in the center of the inner cylinders 51, 56, without
20 coming into contact.
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As can clearly be seen in the sectional illustration in figure 3, the outer rings 48, 53, the intermediate rings 49/54, 50/55, the inner cylinders 51/56 as well
30 as the base plates 47/52 delimit three separate and concentrically arranged annular cutouts which are suitable for accommodating (in each case preferably helical) windings. The individual winding sections of the primary winding and the secondary winding are in
35 this case fixed in circular winding supports, which are in each case made from an electrically insulating material, for example plastic, and are mounted on the inner sides of the base plates. The electrical

connections between the individual, in each case sleeve-shaped winding sections run within the winding supports. Each winding has two winding terminations, which are passed to the outside via the winding support 5 and corresponding openings in the base plate.

An outer winding support 59, which is associated with the primary winding, is fixed to the base plate 47 of the first core half at the location of the outer 10 annular cutout and fixes two winding sections of a primary winding, to be precise

- an outer winding section 62,
- an inner winding section 63.

15 A central winding support 60, which is associated with the primary winding, is fixed to the base plate 47 of the first core half at the location of the central annular cutout and fixes two winding sections of a primary winding, to be precise

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- an outer winding section 64,
- an inner winding section 65.

An inner winding support 61, which is associated with the primary winding, is fixed to the base plate 47 of 25 the first core half at the location of the inner annular cutout and fixes two winding sections of a primary winding, to be precise

- an outer winding section 66,
- an inner winding section 67.

30 An outer winding support 68, which is associated with the secondary winding, is fixed to the base plate 52 of the second core half at the location of the outer annular cutout and fixes two immediately adjacent 35 winding sections 71, 72 of a secondary winding.

A central winding support 69, which is associated with the secondary winding, is fixed to the base plate 52 of

the second core half at the location of the central annular cutout and fixes two immediately adjacent winding sections 73, 74 of a secondary winding.

5 An inner winding support 70, which is associated with the secondary winding, is fixed to the base plate 52 of the second core half at the location of the inner annular cutout and fixes two immediately adjacent winding sections 75, 76 of a secondary winding.

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As is identified in figure 3, the current directions of the winding sections (which lie directly opposite one another so as to form an air gap and are associated alternately with the primary winding and the secondary winding) 62/71, 72/63, 64/73, 74/65, 66/75, 76/67 are in each case opposite one another.

Additional advantages of this embodiment as shown in figure 3:

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- It is also possible for a plurality of DC-isolated primary windings and secondary windings to be provided, i.e. it is possible for a plurality of circuits to be inductively coupled into one and the same rotary transformer.

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- As regards the magnetic flux there is a shortened path length, which reduces the losses and thus increases the degree of efficiency.
- Overall less core material is required for guiding the magnetic flux.

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- In comparison to the exemplary embodiments shown in figure 1 and figure 2, a greater primary/secondary transformation ratio can be selected.

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Figures 4 and 5 illustrate exemplary embodiments with a central hole in the core, to be precise figure 4 essentially corresponds to the embodiment shown in

figure 1 and figure 5 essentially corresponds to the embodiment shown in figure 2.

Figure 4 shows a rotary transformer 77 which has a
5 first core half 78 and a second core half 79, which is formed essentially symmetrically with respect thereto, an air gap 80 being formed between the two core halves, and a central hole 81 being provided in the core halves. A winding system 82, comprising a primary winding and a secondary winding, is located in the annular cutout in the rotary transformer 77, the inner cylinders 4, 7 of the embodiment shown in figure 1 being replaced by inner rings in order to implement the desired central hole 81.

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Figure 5 shows a rotary transformer 83 which has a first core half 84 and a second core half 85, air gaps 86, 87 being formed between the two core halves, and a central hole 88 being provided in the core halves. A 20 winding system 89, comprising a primary winding and a secondary winding, is located in the annular cutout in the rotary transformer 83, the inner cylinder 26 of the embodiment shown in figure 2 being replaced by an inner ring in order to implement the desired central hole 88.

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Where winding sections have been mentioned above, a winding section may alternatively comprise:

- a single turn or
- a plurality of (two, three, four...). turns.

30 The transformation ratio between the primary winding and the secondary winding is in principle freely selectable.

Figure 6 shows the profile of the magnetic field strength over the individual winding sections. If one first considers the exemplary embodiment shown in figure 1, the magnetic field strength over the winding section 11 increases from 0 to the maximum value MAX,

falls to 0 and the minimum value MIN over the winding sections 18 and 19, respectively, increases to 0 and MAX over the winding sections 12 and 13, respectively, falls to 0 and MIN over the winding sections 20 and 21, 5 respectively, increases to 0 and MAX over the winding sections 14 and 15, respectively, and falls to 0 over the winding section 22. An identical profile of the magnetic field strength results over the winding sections 33 - 40 - 41 - 34 - 35 - 42 - 43 - 36 - 37 - 10 44 in the exemplary embodiment shown in figure 2.

Of course, an identical profile for the magnetic field strength is also produced in the exemplary embodiment shown in figure 3: 0 - MAX - 0 - MIN - 0 - MAX - 0 - 15 MIN - 0 - MAX - 0 - MIN - 0 over the individual winding sections 62 - 71 - 72 - 63 - 64 - 73 - 74 - 65 - 66 - 75 - 76 - 67.

It can easily be seen that this zigzag profile for the 20 magnetic field strength (which occurs in all exemplary embodiments) between a maximum value MAX and a minimum value MIN results from the fact that the winding sections of the primary winding and the secondary winding interengage in the manner of a comb, the 25 current flow of immediately adjacent winding sections of the primary winding and the secondary winding in each case being in the opposite direction. If one were to arrange all of the winding sections of the primary winding next to one another and all of the winding 30 sections of the secondary winding likewise next to one another and the primary winding and secondary winding thus formed opposite one another, as is envisaged in EP 0 680 060 A1, the maximum value of the magnetic field strength of a winding distributed in this manner 35 would be a multiple higher than the maximum value which would be achieved in the arrangement according to the invention with winding sections interengaging in the manner of a comb. As a consequence, on the one hand the

transformer losses occurring and on the other hand the leakage field occurring would be a multiple greater. This would thus result in a relatively low degree of efficiency for the rotary transformer.

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In the above embodiments, it has been assumed by way of example that the primary winding and the secondary winding of the rotary transformer are designed for the same power rating. As a deviation from this, embodiments can of course be realized in which the secondary winding of the rotary transformer is designed to have a lower power capacity than the primary winding and is also correspondingly designed to be lighter if only relatively low powers are to be produced on the secondary side. In such an embodiment, the core half of the secondary part can be dispensed with entirely. This embodiment is very advantageous in particular when using the rotary transformer in a robot having a tool replacement device. A tool replacement device allows for various tool arms to be fitted to the robot arm. The various tools have different power consumptions. The secondary sides of the rotary transformer are in each case matched to the specific power requirement of the tool, while the primary side of the rotary transformer remains the same for all different tools (with different power requirements).

In the above embodiments, it has been assumed that the core halves are each of integral design. As a deviation from this, it is also possible, of course, for the core halves or the core to comprise individual segments (for example in the form of "cake slices").

List of reference symbols

- 1 Rotary transformer
- 2 Base plate of the first core half
- 5 3 Outer ring
- 4 Inner cylinder
- 5 Base plate of the second core half
- 6 Outer ring
- 7 Inner cylinder
- 10 8 Air gap
- 9 Axis of rotation
- 10 Winding support of the first core half
- 11 First winding section of the primary winding
- 12 Second winding section
- 15 13 Third winding section
- 14 Fourth winding section
- 15 Fifth winding section
- 16 Winding termination
- 17 Winding support of the second core half
- 20 18 First winding section of the secondary winding
- 19 Second winding section
- 20 Third winding section
- 21 Fourth winding section
- 22 Fifth winding section
- 25 23 Winding termination
- 24 Rotary transformer
- 25 Base plate of the first core half
- 26 Inner cylinder
- 27 Base plate of the second core half
- 30 28 Outer ring
- 29 Air gap
- 30 Air gap
- 31 Axis of rotation
- 32 Winding support of the first core half
- 35 33 First winding section of the primary winding
- 34 Second winding section
- 35 Third winding section
- 36 Fourth winding section

- 37 Fifth winding section
- 38 Winding termination
- 39 Winding support of the second core half
- 40 First winding section of the secondary winding
- 5 41 Second winding section
- 42 Third winding section
- 43 Fourth winding section
- 44 Fifth winding section
- 45 Winding termination
- 10 46 Rotary transformer
- 47 Base plate of the first core half
- 48 Outer ring
- 49 Intermediate ring
- 50 Intermediate ring
- 15 51 Inner cylinder
- 52 Base plate of the second core half
- 53 Outer ring
- 54 Intermediate ring
- 55 Intermediate ring
- 20 56 Inner cylinder
- 57 Air gap
- 58 Axis of rotation
- 59 Winding support of the first core half
- 60 Winding support
- 25 61 Winding support
- 62 First winding section of the primary winding
- 63 Second winding section
- 64 Third winding section
- 65 Fourth winding section
- 30 66 Fifth winding section
- 67 Sixth winding section
- 68 Winding support of the second core half
- 69 Winding support
- 70 Winding support
- 35 71 First winding section of the secondary winding
- 72 Second winding section
- 73 Third winding section
- 74 Fourth winding section

75 Fifth winding section
76 Sixth winding section
77 Rotary transformer
78 First core half
5 79 Second core half
80 Air gap
81 Central hole
82 Winding system
83 Rotary transformer
10 84 First core half
85 Second core half
86 Air gap
87 Air gap
88 Central hole
15 89 Winding system